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**NORTHROP** Electronics Division

- [ ] This submittal applies to AN/BRN-7 (Submarine Ω) only.
- [ ] This submittal applies to AN/SRN-( ) (Hydrofoil Ω) only.
- [X] This submittal applies to both AN/BRN-7 and AN/SRN-( ).

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**NORTHROP**

**Electronics Division**

Copy No. 1

NORT 73-48

AN/BRN-7 COMPUTER
*PROGRAM SPECIFICATION*

Volume V

TRACKING FILTER SUBPROGRAM DESIGN

October 12, 1973



Approved by

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Volume V
of the

AN/BRN-7 OMEGA COMPUTER
PROGRAM SPECIFICATION

## CONTENTS

# SECTION 1

# SCOPE

## 1.1 IDENTIFICATION

Volume I, Submarine OMEGA Computer Program Performance Specification, defines the functional requirements for the Submarine OMEGA Computer Program which is used by the AN/ARN-99 OMEGA Navigation Set. The Navigation Set and the OMEGA program together comprise the Submarine OMEGA Navigation System. The tape which defines the computer program is entitled AN/BRN 7 Navigation Program.

Volume II, Submarine OMEGA Computer Program Design Specification, allocated the functional requirements of Volume I to the computer routine and subprogram level.

This volume describes the subprogram designated as Tracking Filter, which has the abbreviation TF in the program listing (Volume XIII).

## 1.2 TRACKING FILTER SUBPROGRAM TASKS (Figure 1)

a) Initialization/Reinitialization: The procedures for initialization and reinitialization are used at start-up, when the velocity sources for the calculations are changed; whenever a change in the base station is indicated, or whenever initial time or initial position is inserted. The operations involved include combinations of: setting the n-counters to zero, and resetting the phase-difference variances, the phase-difference rate variances,and the cross-variances.

b) Time Updating of Variance: All Tracking Filters are time updated at the end of every OMEGA burst. This includes the variance on the phase-difference estimate, and if this is too large then the cross-variance is also reset. Similarly the variance on the phase-difference rate is time updated, and if too large, then again the cross-variance is reset.

c) Time Updating of Phase Rate: Phase Rate is time updated after the variance time update for each station-to-base pair. Using station coordinates and velocity components, the phase rate for the base is calculated and this, in turn, will be used to correct the phase rate on the station-to-base phase-rate estimate.

d) Time Updating of Phase Estimate: The phase difference estimate is iterated once for each station and base station combination at the end of each burst (24 times in a 10-second cycle).

TRACKING FILTER

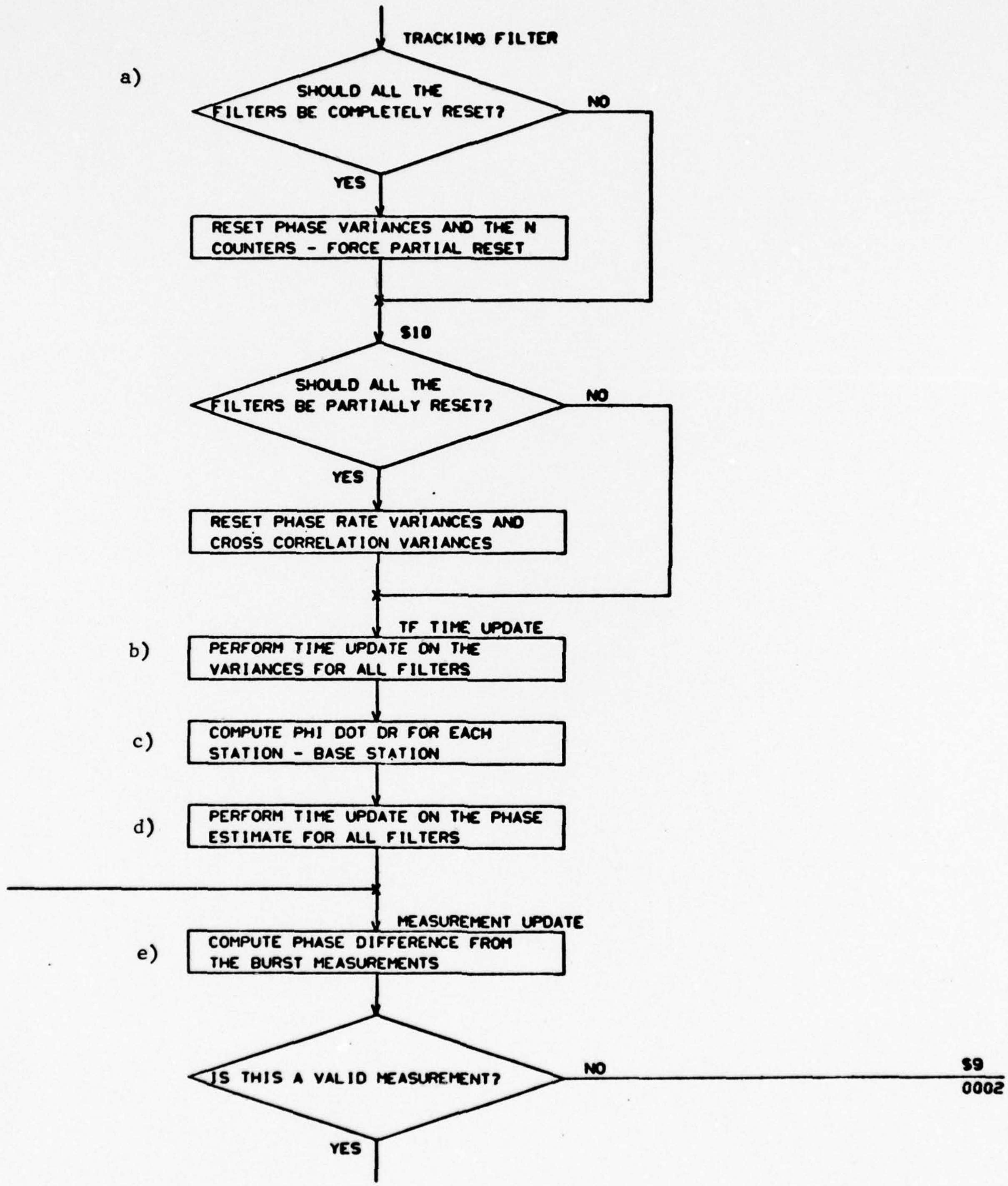



FIGURE 1 (Sheet 1)

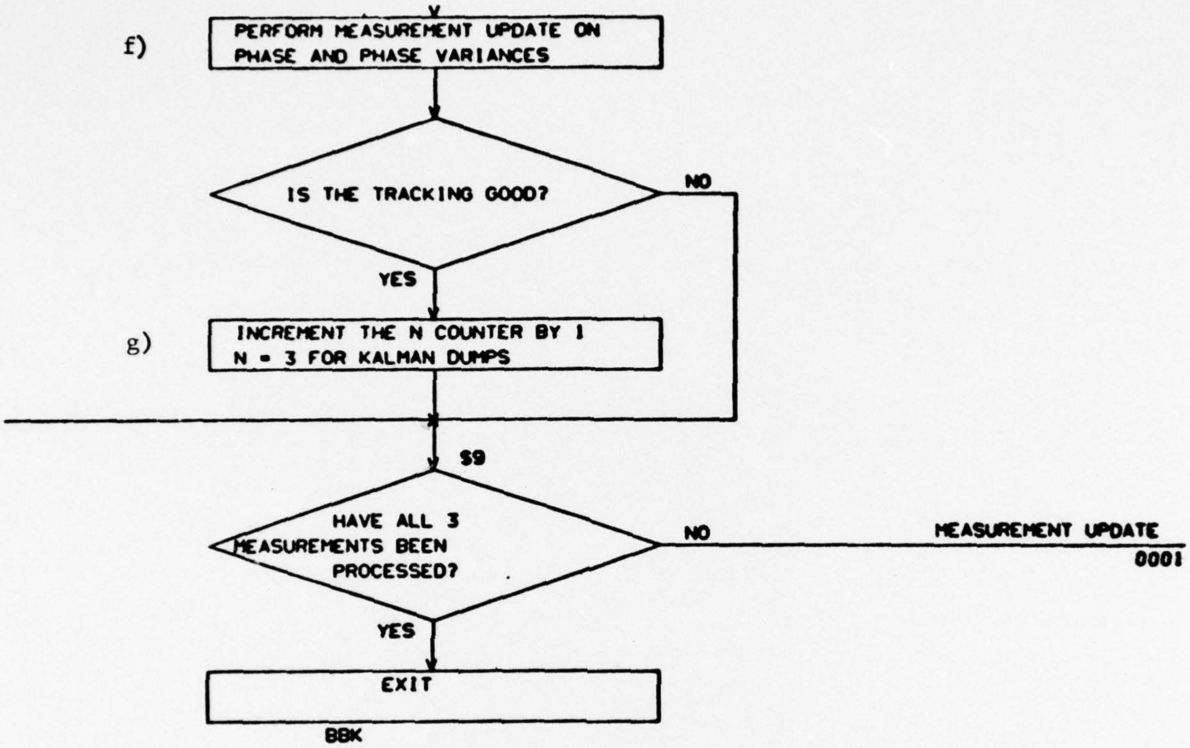



FIGURE 1 (Sheet 2)

e) Phase Differencing: Using RAW H, which is the three-frequency burst element from END BURST, determine whether to light the SIGNAL LOSS indicator, and then smooth RAW H with previous data. Difference the burst phase with that from the station designated as base, then add their variances. Or if the present station is the base station then save for base station phase rate updating.

f) Measurement Update: A measurement update occurs if the variance from the phase differencing process is less than one square cycle. The difference between the estimate of phase difference and raw measurement from the OMEGA PROCESSING routine is used to make the filter adaptive; the variances increase in proportion to the amount of disagreement.

The correction term, $\theta$ , must be calculated. The phase-difference rate variance is measurement updated, and then the phase-difference estimate is measurement updated, as well as its variance.

g) Increment n-Counters: Test the variance on the phase-estimate and phase-difference rate estimate. If within the criteria, set the increment n-counters.

# SECTION 2

## APPLICABLE DOCUMENTS

a) Submarine OMEGA Computer Program Performance Specification, Volume I of the Submarine OMEGA Computer Program Specification.

Applicable Sections:

3.1 Introduction

3.2 Functional Description
  3.2.5 Detailed System Operations

3.3 Detailed Functional Requirements
  3.3.8 Base Station Selection
  3.3.9 Phase Difference Function
  3.3.10 Tracking Filters

b) Submarine OMEGA Computer Program Design Specification, Volume II of the Submarine OMEGA Computer Program Specification.

3.3 Subprogram Description and Allocation of Requirements

c) NORT 68-66, NAP70 User's Manual, July 1968.

d) NORT 68-115A, Detailed Description of NDC-1070 Computer Instructions, Revision A, February 1970.

e) NORT 69-87A, NDC-1070 Flow Chart Program, User's Manual.

NOTE: The data base for each subprogram is included in the appropriate volume.

# SECTION 3

# REQUIREMENTS

In order to understand the program description contained in the following pages, it is necessary that the reader will have become familiar with the associated functional requirements found in Volume I, Performance Specification, and with the subprogram allocation found in Volume II, Design Specification.

## 3.1 DETAILED DESCRIPTION

### 3.1.1 Reference Labels to Flow Diagrams

The code used to reference the particular block in the flow diagrams, Section 3.2, is as follows: The first number, preceded by a p, is the page number found in the upper right corner of the diagrams. This will be followed by a slash sign (/) to separate the page number from the block designator. The designator will either be a mnemonic label (e.g., TEST SYNC), a local label indicated by a dollar sign ($), or an integer. The two types of labels reference the particular information block, on the given page, to which the label is attached. The integer number, n, means that the referenced block is the nth block from the top of the page; p8/3 would refer to page 8 and the third information block down.

Finally, the label P1/$2+3 refers to page 1, and the 3rd information block after the label $2. Similarly, P2/7,8,9 refers to Page 2 and blocks 7 through 9.

### 3.1.2 Overview

It is desirable to further process the measurements from OMEGA PROCESSING in order to develop more accurate and usable values. This is accomplished in the Tracking Filters. Successive phase measurements from OMEGA PROCESSING for each transmitting station and each frequency are combined in separate Tracking Filters. Since there are 8 possible transmitting stations and 3 frequencies processed in the receiver, there are 24 Tracking Filters.

Each Tracking Filter receives an input from OMEGA PROCESSING every 10 seconds. This input consists of a measure of phase and a computed variance of this measurement. The Submarine OMEGA Navigation System uses a hyperbolic navigation concept. Consequently, each burst phase from station i is combined with the last incoming burst phase from the station designated as the base station, and usually subscripted by k. The result of this is a measurement of phase difference. This measured phase difference $\phi_{ik}$ (freq) is then compared (or weighted in a statistical sense) with an

estimated value of phase $\hat{\phi}_{ik}$ (freq) which the Tracking Filter computes based upon previous measurements. From this comparison a new estimate of phase is computed.

Henceforth the frequency dependence of the symbols will be dropped for convenience, so that $\phi_{ik}$ (freq) will be represented as $\phi_{ik}$. It is understood that the operations involved apply to not one but three frequencies.

In order to compare or statistically average successive phase difference measurements spaced 10 seconds apart in time, it is necessary to remove the effect of the change in phase due to the submarine change in position. This is referred to as rate-aiding. Velocity information is obtained from a velocity source external to the OMEGA receiver (E.M. Log Repeater or manual insert). The velocity inputs to the Tracking Filter consist of the $V_2$ and $V_3$ components of the raw velocity as computed by the velocity processing equation. OMEGA velocity corrections are not used in Tracking Filters. The Tracking Filter then computes the component of velocity along the direction from submarine to transmitting station, then to the base station, and then converts to an equivalent dead reckoning phase rate, $\dot{\phi}_{DR}$. This phase rate is then used to update the Tracking Filter phase-difference estimate $\hat{\phi}$.

Besides estimating phase differences, the Tracking Filter also estimates phase-difference rate error, $\Delta\dot{\phi}$. This is the error in phase rate as computed from the velocity sources. The estimated phase-difference rate error $\Delta\dot{\phi}$ is used to correct the computed phase-difference rate $\dot{\phi}_{DR}$ in the time update of the estimate.

In addition to computing $\hat{\phi}$ and $\widehat{\Delta\dot{\phi}}$, the Tracking Filter also computes the following variances:

a) $\sigma^2_{\phi\phi}$ , the variance of the error in estimating phase-difference

b) $\sigma^2_{\dot{\phi}\dot{\phi}}$ , the variance of the error in estimating phase-difference rate error

c) $\sigma^2_{\phi\dot{\phi}}$ , the cross-variance of errors in estimating both.

It is the computation of these variances along with $\sigma^2_{ik}$ from burst measurements that allows the filter to statistically average $\phi_{ik}$ and $\hat{\phi}_{ik}$ and obtain better estimates of $\hat{\phi}_{ik}$ and $\Delta\dot{\phi}_{ik}$. The three variances listed above are updated and recomputed at every phase measurement.

The outputs of the Tracking Filters are $\hat{\phi}$, $\sigma^2_{\phi\phi}$ (station and base subscripts omitted) for each station-base or base-base pair. These outputs are the inputs to the Combinational Filter. The Combinational Filter combines the outputs of the Tracking Filters to obtain position estimates. When $\sigma^2_{\phi\phi}$ has reached a value of less than 3 $cec^2$ and $\sigma^2_{\dot{\phi}\dot{\phi}}$ is less than $(0.03\ cec/sec)^2$ for three consecutive Burst Filter measurements, the phase

estimate is considered accurate enough to be used by the Combinational Filter. A counter (called the n counter) is used as a flag to tell the Combinational Filter when to read the Tracking Filter outputs.

With every phase difference measurement the counter is incremented if $\sigma^2_{\phi\phi}$ and $\sigma^2_{\dot{\phi}\dot{\phi}}$ are both less than their respective limits, otherwise the counter is reset to zero. When the counter reaches three, the Tracking Filter is ready to be read. The Combinational Filter will then read the $\hat{\phi}$ and $\sigma^2_{\phi\phi}$ from the Tracking Filter. Until the Tracking Filter outputs are read the Tracking Filter continues to operate in a normal manner. When the outputs are read, the n counter is reset to zero and the Tracking Filter is reset. It is desirable for each reading from a given Tracking Filter to be statistically independent from the others. For this reason, the Tracking Filter variances are reset to their initial values after being read by the Combinational Filter. These values assure independence of Tracking Filter outputs.

The statistical derivation of the Tracking Filter equations is given in Appendix A, Volume I.

### 3.1.3 Description of Flow Diagrams

The following description is by the task sequence outlined in 1.2.

The Submarine OMEGA Computer Program Functional Requirements were defined in Volume I, Performance Specification, and allocated to Subprograms in Volume II, Design Specification. The Tracking Filter Subprogram has combined portions of these requirements. Those affected are summarized here.

| Paragraph in this section | Functional Requirement |
|---|---|
| e 1) | 3.3.8 Base Station Selection<br>item 3.3.8.3.1-c<br>3.3.8.3.2-b |
| e 2) | 3.3.9 Phase Difference Function |
| All others | 3.3.10 Tracking Filter Requirement |

a) Initialization/Reinitialization

p1/Tracking Filter

to

p2/TF Time Update

1) The Initialization/Reinitialization procedures are used:

   a. At start-up

   b. When the velocity sources for the calculations are changed

   c. When the Combinational (Kalman) Filter uses a Tracking Filter output (See note for 1c, below)

   d. Whenever a change in the base station is indicated

   e. Whenever initial time or initial position is entered.

2) The procedures for the above are as follows:

   a. Set all n-counters to zero

   b. Set $\sigma^2_{\phi\phi} = \frac{1}{12}$

   c. Set $\sigma^2_{\phi\dot{\phi}} = 0$

   d. Set $\sigma^2_{\dot{\phi}\dot{\phi}} = (0.006\,\pi)^2$

   For 1a; 1d; 1e, reset all tracking filters by 2a through 2d.

   For 1b, reset all tracking filters by 2c and 2d.

   For 1c, reset only the selected filter, using 2a through 2d.

NOTE: For 1c, the Combinational Filter resets only the selected filter and effectively accomplishes 2a through 2d, but does not use the Tracking Filter reinitialization procedures.

b) Time Updating of Variance

p2/TF Time Update

to

P3/$3 + 5

All Tracking Filters are time updated at the end of every OMEGA burst. The following equations are computed in the order indicated.

1) $\sigma^2_{\phi\phi}(k) = \sigma^2_{\phi\phi}(k-1) + 2\,\sigma^2_{\phi\dot{\phi}}(k-1)\,\Delta t_k + \sigma^2_{\dot{\phi}\dot{\phi}}(k-1)\,(\Delta t_k)^2$

Test: is $\sigma^2_{\phi\phi}(k) > 1\ (\text{cycle})^2$

Yes. Then set $\sigma^2_{\phi\phi}(k) = 1\ (\text{cycle})^2$

$$\sigma^2_{\phi\dot{\phi}}(k) = \sigma^2_{\phi\dot{\phi}}(k-1)/2$$

go to (2)

No. Then $\sigma^2_{\phi\dot{\phi}}(k) = \sigma^2_{\phi\dot{\phi}}(k-1) + \sigma^2_{\dot{\phi}\dot{\phi}}(k-1)\,\Delta t_k$

2) $\sigma^2_{\dot{\phi}\dot{\phi}}(k) = \sigma^2_{\dot{\phi}\dot{\phi}}(k-1) + r^2$

Test: is $\sigma^2_{\dot{\phi}\dot{\phi}}(k) > \dfrac{1}{2\pi^2}\left(\dfrac{\text{cycle}}{\text{sec}}\right)^2$

Yes. Then set $\sigma^2_{\dot{\phi}\dot{\phi}} = \dfrac{1}{2\pi^2}$

$$\sigma^2_{\phi\dot{\phi}}(k) = \frac{\sigma^2_{\phi\dot{\phi}}(k)}{2}$$

and continue.

No. Then continue.

c) Time Update of Phase Rate

p4/$1 to p6/$6

Processed after variance update for each station and base-station pair.

1) Station coordinates; earth fixed to local level coordinates. Obtain for station and base.

$$SL_{2i} = \sum_{f=1}^{3} r_{2f}\, S_{fi}$$

$$SL_{3i} = \sum_{f=1}^{3} r_{3f}\, S_{fi}$$

$i$ = 1, ... 8 (station)

$r_{ij}$ = Element in the $i^{th}$ row and $j^{th}$ column of the $R_{ij}$ matrix from which vehicle position is computed.

2) $\dot{\phi}_{DR}$ Determination; obtain $\dot{\phi}_{DR}$ (station) and $\dot{\phi}_{DR}$ (base)

$$\dot{\phi}_{DR_{ii}} = - \frac{V_3\, SL_{3i} + V_2\, SL_{2i}}{\left( SL_{3i}^2 + SL_{2i}^2 \right)^{1/2}}$$

Since the filters are tracking an angle that represents the phase of station i at time t minus the phase of the base station at some earlier time, it is necessary to make the following correction for arrival at the final value of $\dot{\phi}_{DR}$ for each Tracking Filter:

$$\dot{\phi}_{DR_{ik}} = \dot{\phi}_{DR_{ii}}(t) - \dot{\phi}_{DR_{kk}}(t-t')$$

where
- i = station number
- j = frequency
- k = base station number
- t = time
- t' = time delay between base station burst and station i burst for this frequency (if i=k then t-t= 10 sec)

For computational purposes it would be adequate to set t' = 0 in all cases.

d) Time Update of Phase Estimate

p6/$2 to p6/Measurement Update

The phase difference estimate is iterated once for each station and base station combination at the end of each burst (24 times in a 10-second cycle).

$$\hat{\phi}(k) = \hat{\phi}(k-1) + \Delta t_u \left[ \frac{\lambda 3}{\lambda i} \dot{\varphi}_{DR}(k) + \hat{\Delta \dot{\phi}}(k-1) \right]$$

where $\Delta t_u$ = time period since last update.

If $\Delta t_b$ is interval of previous burst then

$\Delta t_u = \Delta t_b + 0.4$ sec.

e) Phase Differencing

p6/Measurement Update to p10/$21 + 1

1) For station i, obtain $RH_i$ from OMEGA Processing $(=Q_{mi}(f_1)\ Q_{mi}(f_2)\ Q_{mi}(f_3))$.

Perform a simple smoothing operation on resultant

$$SRH_i = SRH_i + 0.1\ (RH_i - SRH_i)$$

If $SRH_{base} \le 0.0078125$ then set SIG LOSS marker and continue normal operation, otherwise continue.

2) Phase Difference Calculation: The following procedures, though indicated for one input only, are done three times per each burst period; 24 per 10-second OMEGA cycle.

Determine station and frequency of input. Is input phase measurement from base station? (check BASE)

No. Then difference input phase measurement $\varphi_a$ with last stored base station phase value $\varphi_b$, where $\phi_i$ represent the $\phi_m$ value from station i on the associated frequency; from burst processing.

$$\phi_{ab} = \phi_a - \phi_b$$

Then combine the associated variances as indicated.

$$\sigma_{ab}^2 = \sigma_a^2 + \sigma_b^2$$

where $\sigma_i^2$ represents $\sigma_{\phi_m}^2$ station i on associated frequency; from burst processing.

Yes. Then difference input base station measurement with last stored base station phase value. Combine the variances as indicated.

$$\phi_{bb} = \phi_b(\text{input}) - \phi_b\ (\text{stored})$$

$$\sigma^2_{bb} = \sigma^2_{bb}(\text{input}) + \sigma^2_{bb}(\text{stored})$$

Then replace reference base station phase value and variance with input values.

f) Measurement Update

p11/1 to 3

A measurement update is permitted to occur if the variance from OMEGA Processing is less than one square cycle. The difference between the estimate of phase difference, $\hat{\phi}$, and the raw measurement, $\phi_{ik}$, is used to make the filter adaptive; the variances increase in proportion to the amount of disagreement. Since $\phi_{ik}$ is a value averaged over the time interval $\Delta t_u$ while $\hat{\phi}$ is updated by rate aiding to the end of the time interval, $\hat{\phi}$ is adjusted to make it correspond to near the middle of the interval. This explains the correction term in the equation for the angular difference $\theta$.

1) Angular Difference Correction

$$\theta = \phi_m - \hat{\phi} + \left[ \frac{\lambda 3}{\lambda_i} \dot{\phi}_{DR} + \widehat{\Delta \dot{\phi}} \right] (0.425)$$

(The subscripts will be dropped for this subsection with the understanding that the equations will be computed for the particular station-base-frequency pairs for which $\phi_{ik}$ is available in this time slot.)

Computational parameters

$\Delta t_m$ = 10 seconds

C = $\cos \theta$

S = $\sin \theta$

2) Phase Rate Update

$$L_3 = \sigma^2_{\phi\phi} - \sigma^2_{\phi\dot{\phi}} \Delta t_m + \sigma^2_{ik}$$

NOTE: $L_2$ and the 2nd term of $\hat{\Delta\dot{\phi}}$ (k+1) are computed by the L ALPHA Subroutine, page 15.

$$L_2 = \frac{\sigma^2_{\dot{\phi}\dot{\phi}} \Delta t_m \left[\sigma^2_{\phi\dot{\phi}} \Delta t_m + L_3 C\right]}{\left[L_3 + \sigma^2_{\phi\dot{\phi}} \Delta t_m C\right]^2 + \left[\sigma^2_{\phi\dot{\phi}} \Delta t_m S\right]^2}$$

(If $L_2 > 2$ then set $L_2 = 2$ ; computed in the L ALPHA Subroutine)

$$\hat{\Delta\dot{\phi}}(k+1) = \hat{\Delta\dot{\phi}}(k) + \frac{1}{\Delta t_m} \tan^{-1} \frac{\sigma^2_{\phi\dot{\phi}} \Delta t_m S}{L_3 + \sigma^2_{\phi\dot{\phi}} \Delta t_m C}$$

TEST:

is $|\hat{\Delta\dot{\phi}}| >$ 4 dec's/sec

Yes. Then set $\hat{\Delta\dot{\phi}} = 0$ and continue

No. Then continue

p11/4 to 8

$$\sigma^2_{\dot{\phi}\dot{\phi}}(k+1) = \sigma^2_{\dot{\phi}\dot{\phi}}(k) \frac{L_2^2}{(\Delta t_m)^2} \left[\sigma^2_{\phi\phi}(k) + \sigma^2_{ik}\right] - \frac{2L_2 \sigma^2_{\phi\dot{\phi}}(k)}{\Delta t_m}$$

If $\sigma^2_{\dot{\phi}\dot{\phi}}(k+1) = \frac{1}{2\pi^2}$ then set $\sigma^2_{\dot{\phi}\dot{\phi}}(k+1) = \frac{1}{2\pi^2}$

p12/1,2

NOTE: $L_1$ and the 2nd term of the $\hat{\phi}$ (R+1) equation are computed in the L ALPHA subroutine, page 15.

$$L_1 = \frac{\sigma^2_{\phi\phi}\left[\sigma^2_{\phi\phi} + \sigma^2_{ik} C\right]}{(\sigma^2_{ik} + \sigma^2_{\phi\phi} C)^2 + (\sigma^2_{\phi\phi} S)^2}$$

(If $L_1 > 1$ then set $L_1 = 1$)

3) Update of Phase Estimates

p12/3

$$\hat{\phi}(k+1) = \hat{\phi}(k) + \tan^{-1}\frac{\sigma^2_{\phi\phi}\,S}{\sigma^2_{ik} + \sigma^2_{\phi\phi}\,C}$$

4) Cross Variance Update

p12/4

$$\sigma^2_{\phi\dot{\phi}}(k+1) = (1-L_1)\left[\sigma^2_{\phi\dot{\phi}}(k) - \frac{L_2}{\Delta t_m}\,\sigma^2_{\phi\phi}(k)\right] + \frac{L_1\,L_2\,\sigma^2_{ik}}{\Delta t_m}$$

5) Update of Variance of the Phase-Difference Estimate

p12/\$3 to P13/\$5

$$\sigma^2_{\phi\phi}(k+1) = (1-L_1)^2\,\sigma^2_{\phi\phi}(k) + L_1^2\,\sigma^2_{ik}$$

If $(1-L_1)2\,\sigma^2_{\phi\phi}(k+1) > 1\ (\text{cycle})^2$ then set $\sigma^2_{\phi\phi}(k+1) = 1$

g) Increment n-Counters

p13/\$5+1 to p14/\$8

Test

Is $\sigma^2_{\phi\phi} \leq (3.\ \text{cec})^2$ and $\sigma^2_{\dot{\phi}\dot{\phi}} \leq (0.03\ \text{cec})^2$

Yes: then increment n-counter by +1

No: then reset n-counter to zero

when Measurement Update iterations have been completed and n-counters have been incremented, then exit.

Additional Note: A Tracking Filter Functional Requirement is the integral Lane Count Check (found in paragraph 3.3.10 (c) 4, Volume 1) which requires that periodically the Tracking Filter will compare its phase difference estimate (in cec's) with the phase difference estimate from the propagation prediction routine.

This requirement has been allocated to PROPAGATION PREDICTION. This means that it cannot be represented in the Tracking Filter flow diagram, since the time of occurrence is not precisely known.

### 3.1.4 Description of Subroutines Used by the Tracking Filter Subprogram

a) L ALPHA (page 15)

This subroutine accepts three arguments ($\theta$, B, and A) and returns ALPHA and L.

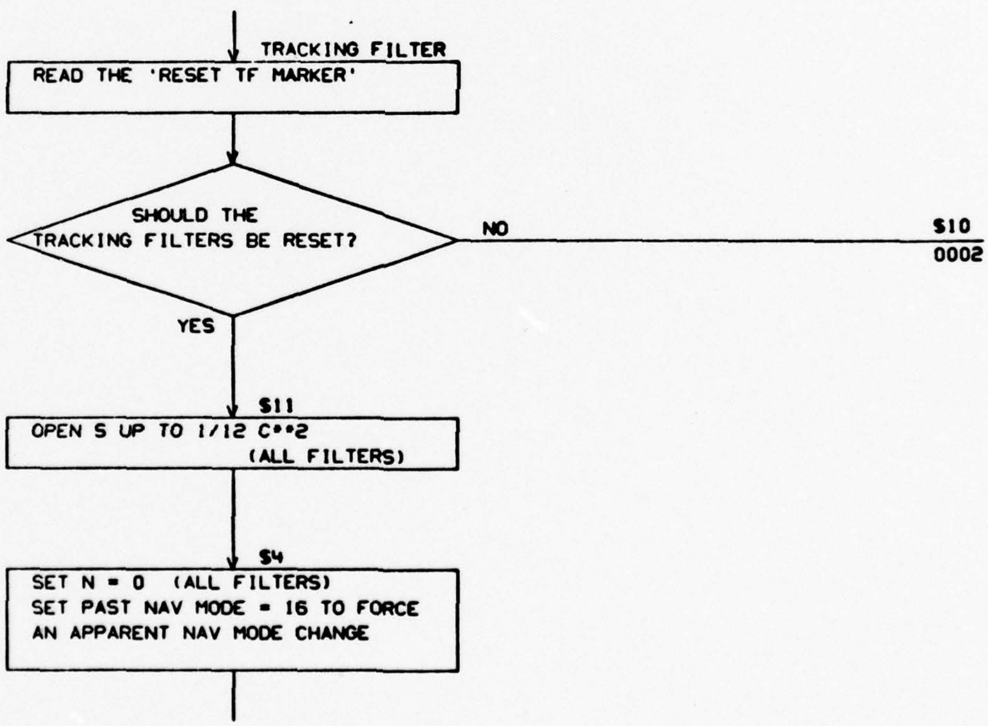
$$L = \frac{(A \cos \theta + B)\ B}{(A + B \cos \theta)^2 + (B \sin \theta)^2}$$

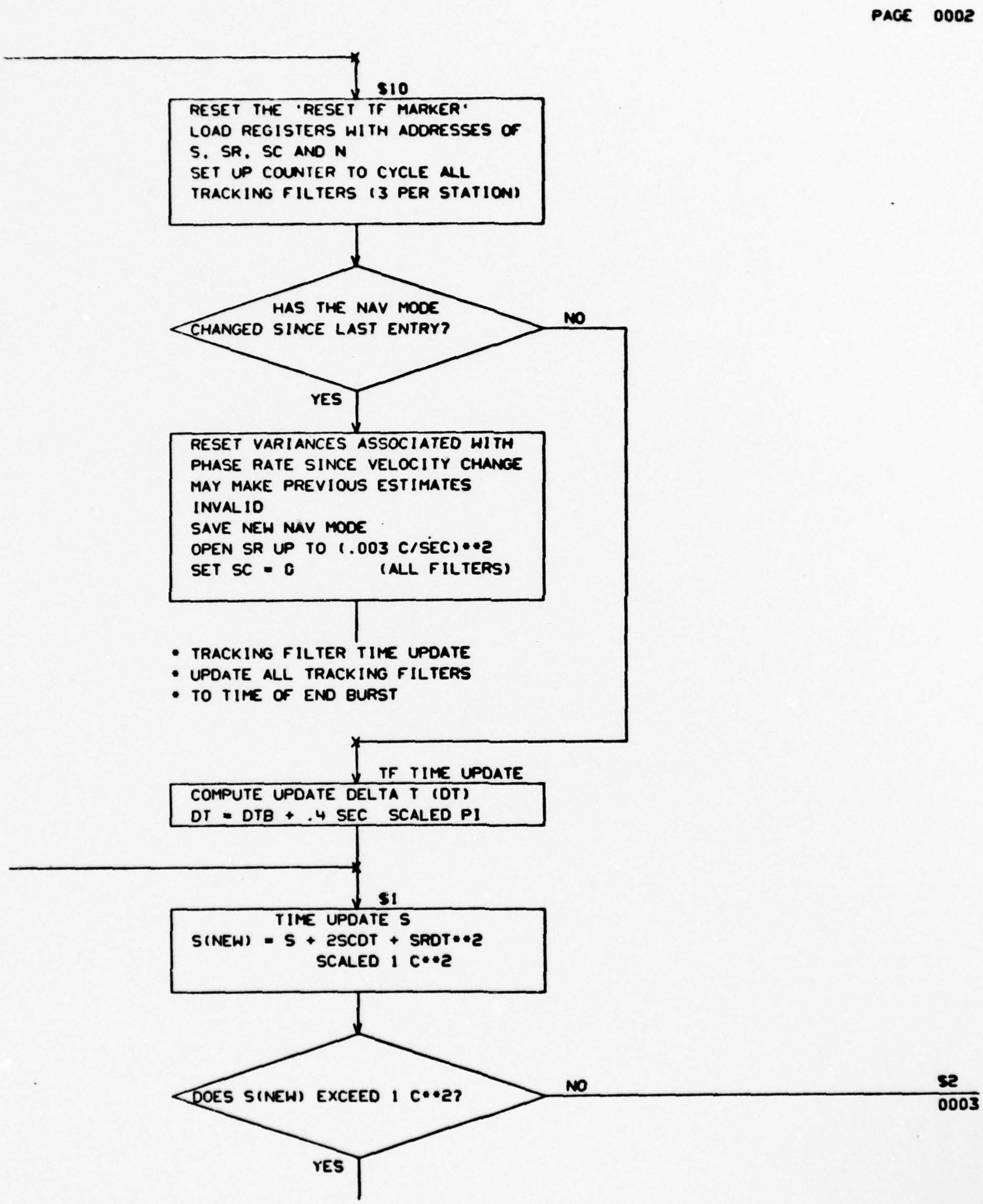
$$\text{ALPHA} = \tan^{-1} \left( \frac{B \sin \theta}{A + B \cos \theta} \right)$$

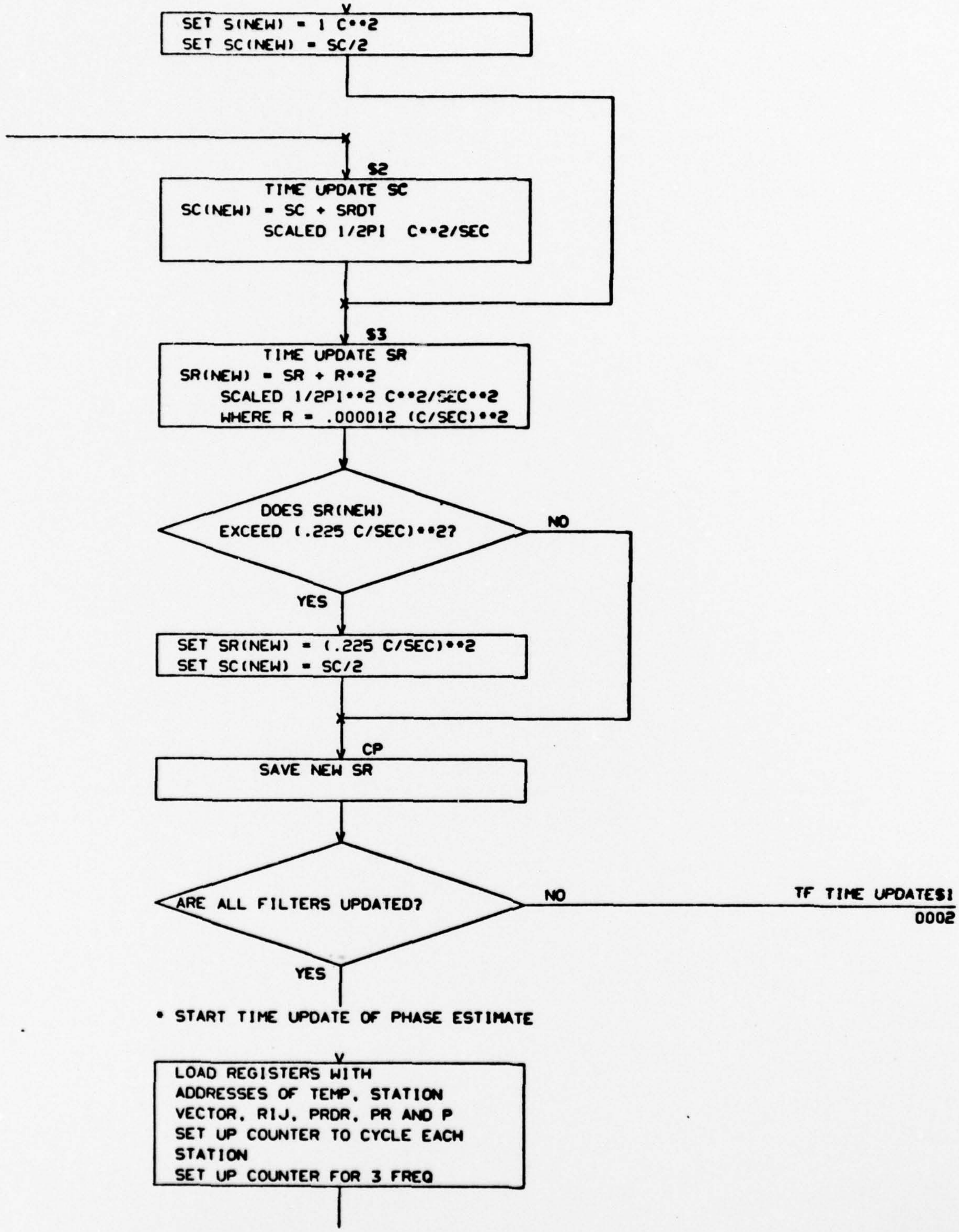
## 3.2 FLOW CHARTS

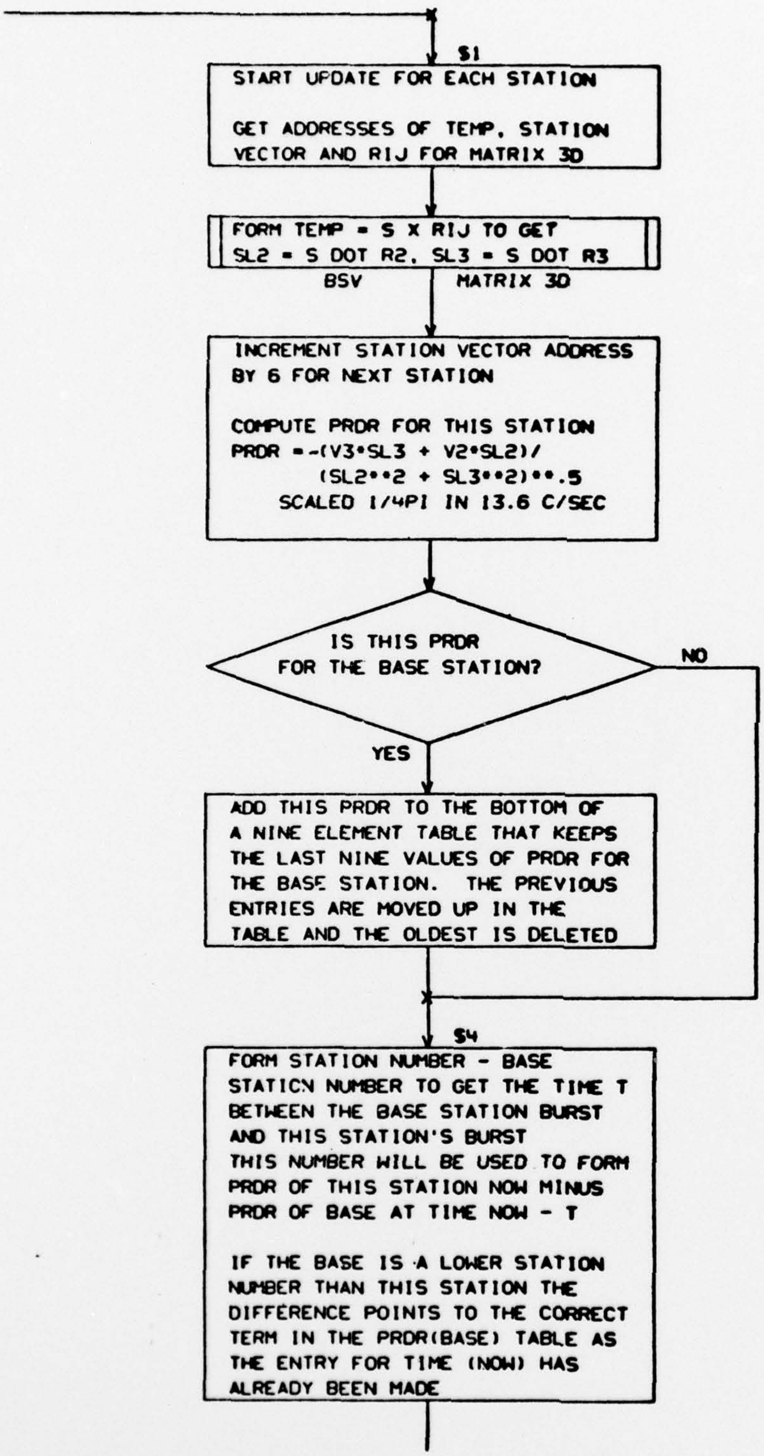
The Tracking Filter Subprogram flow charts are presented in the following pages.

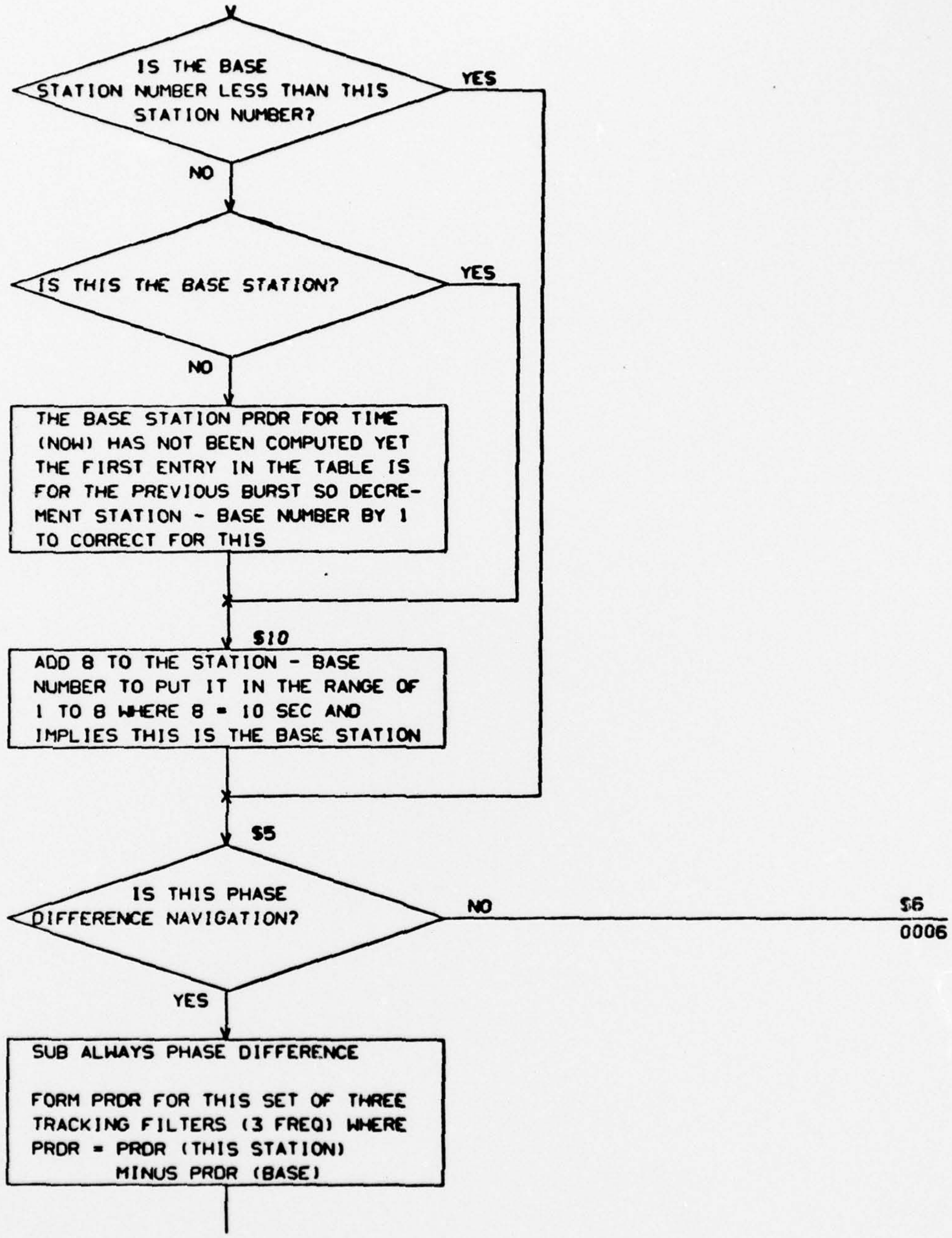
```
*                              TRACKING FILTER
*
* THIS PROGRAM IS EXECUTED AT THE END OF EVERY STATION BURST.
* IT SMOOTHES THE COMPUTED PHASE AND PROVIDES OUTPUTS TO KALMAN.
*
* FOR NOTATIONAL PURPOSES THE SYMBOLS LISTED BELOW WILL BE USED
*
* PB       = BURST PHASE MEASUREMENT
* SB       = BURST PHASE MEASUREMENT VARIANCE
* P        = TRACKING FILTER PHASE ESTIMATE
* PR       = TRACKING FILTER PHASE RATE ESTIMATE
* PRDR     = PHASE RATE DUE TO CRAFT MOTION TOWARDS THE STATION
* DTB      = DELTA T BURST
* DT       = TIME BETWEEN TRACKING FILTER TIME UPDATES
* S        = TRACKING FILTER PHASE ESTIMATE VARIANCE
* SR       = TRACKING FILTER PHASE RATE ESTIMATE VARIANCE
* SC       = CROSS CORRELATION OF PHASE AND PHASE RATE VARIANCE
* C        = CYCLE
* N        = TRACKING FILTER N COUNTERS
* DTM      = TIME BETWEEN TRACKING FILTER MEASUREMENTS (10 SECONDS)
*
```

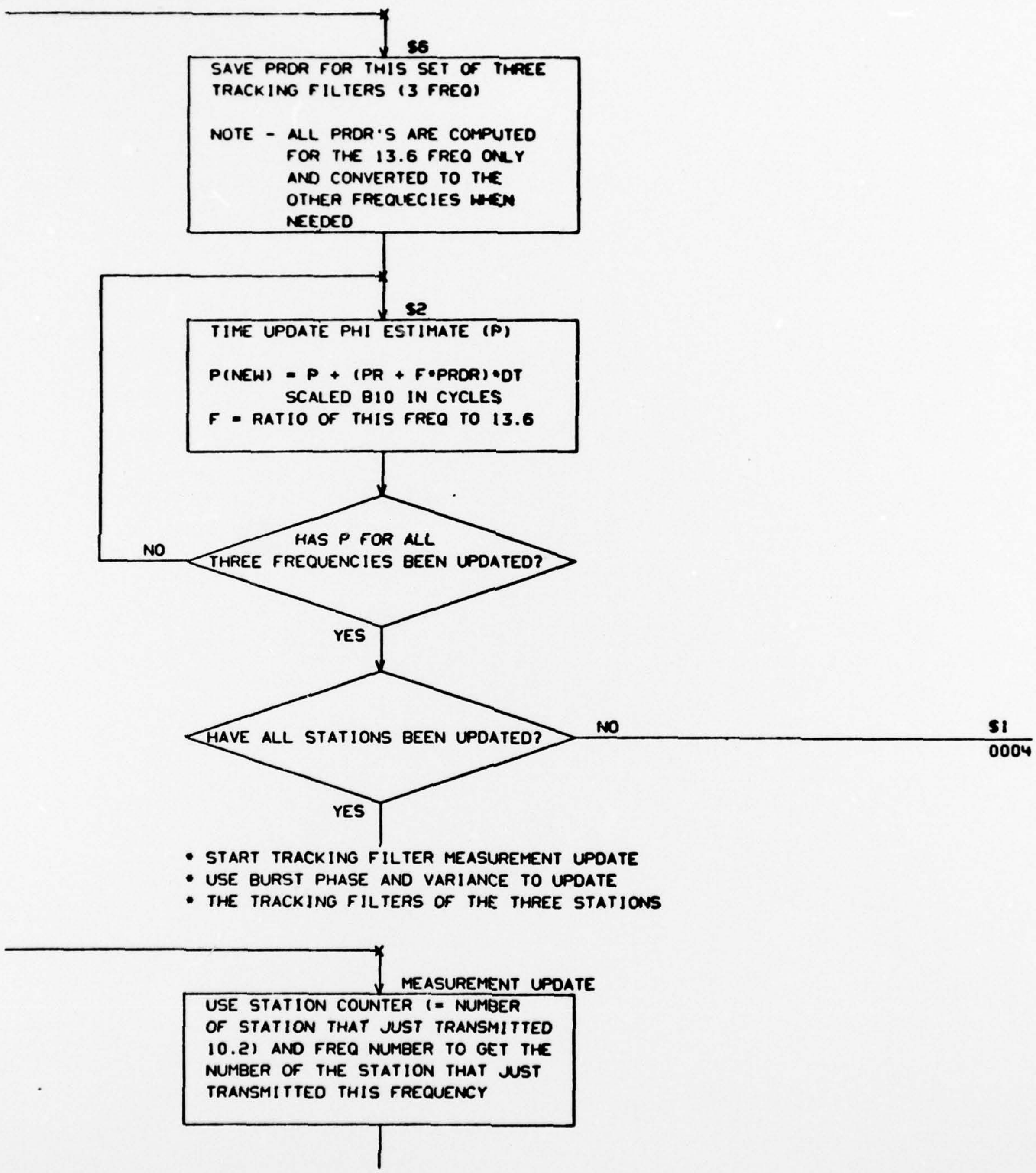


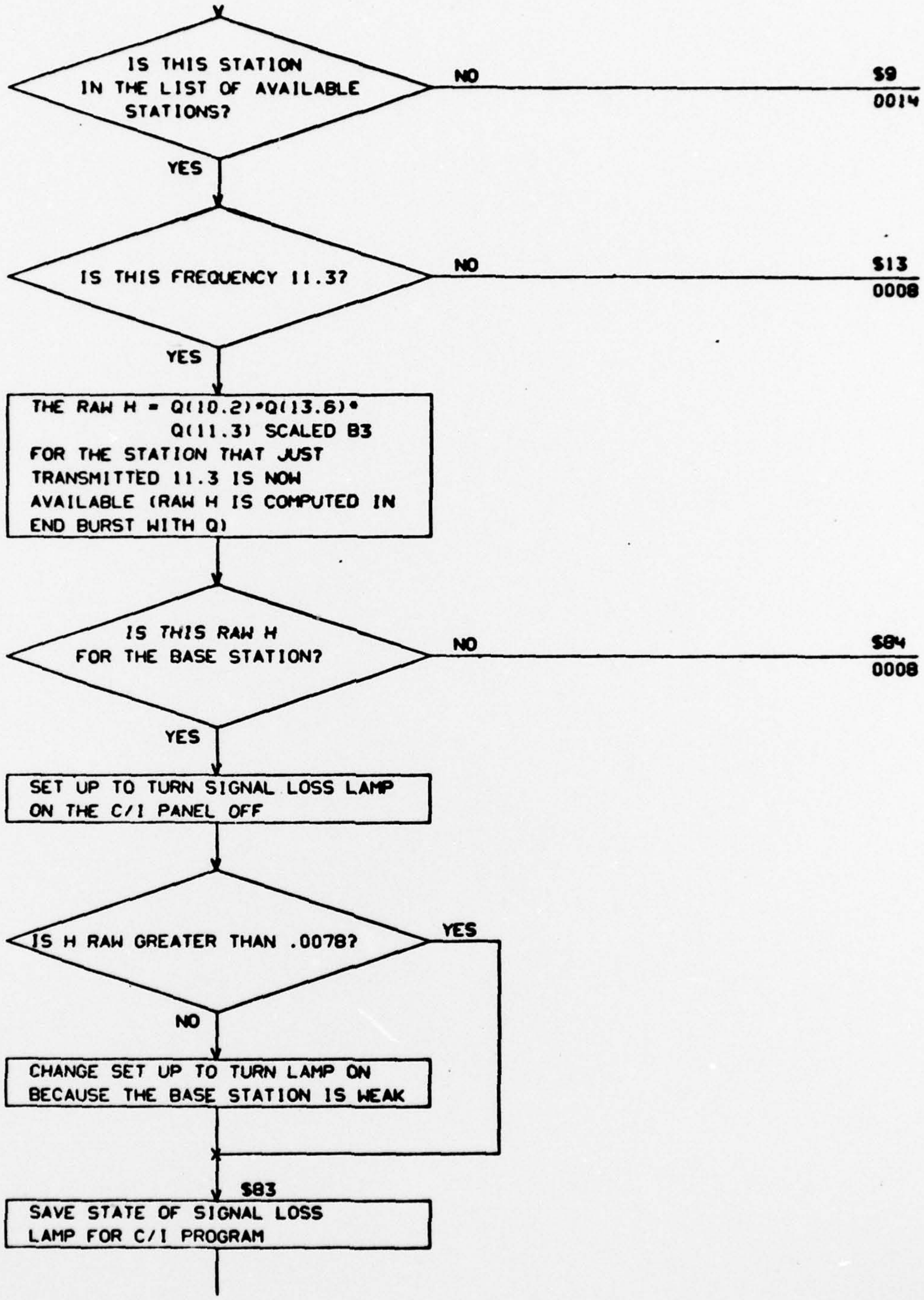

PAGE 0002
$10
RESET THE 'RESET TF MARKER'
LOAD REGISTERS WITH ADDRESSES OF
S, SR, SC AND N
SET UP COUNTER TO CYCLE ALL
TRACKING FILTERS (3 PER STATION)
HAS THE NAV MODE
CHANGED SINCE LAST ENTRY?
NO
YES
RESET VARIANCES ASSOCIATED WITH
PHASE RATE SINCE VELOCITY CHANGE
MAY MAKE PREVIOUS ESTIMATES
INVALID
SAVE NEW NAV MODE
OPEN SR UP TO (.003 C/SEC)**2
SET SC = 0 (ALL FILTERS)
* TRACKING FILTER TIME UPDATE
* UPDATE ALL TRACKING FILTERS
* TO TIME OF END BURST
TF TIME UPDATE
COMPUTE UPDATE DELTA T (DT)
DT = DTB + .4 SEC SCALED PI
$1
TIME UPDATE S
S(NEW) = S + 2SCDT + SRDT**2
SCALED 1 C**2
DOES S(NEW) EXCEED 1 C**2?
NO
$2
0003
YES

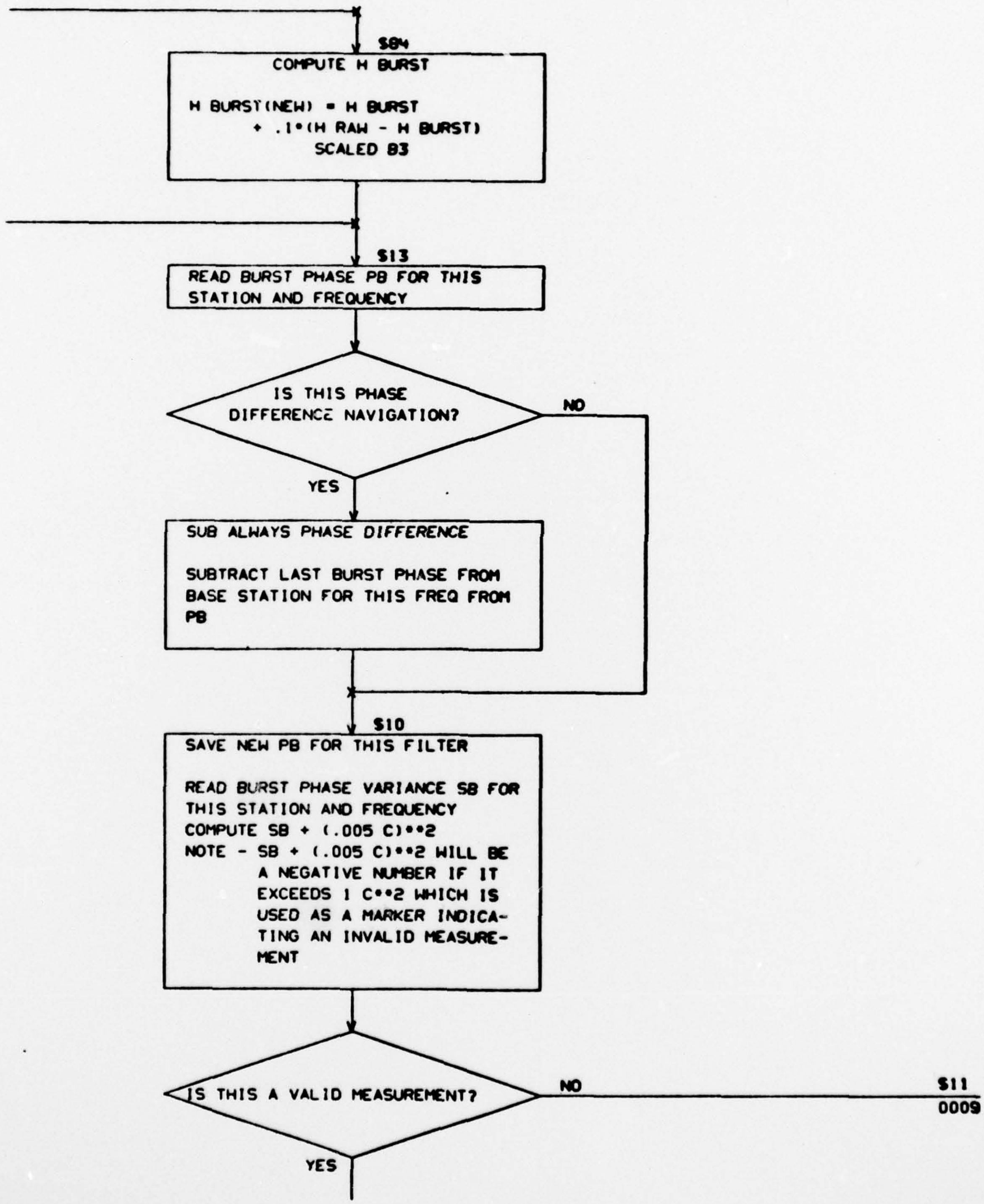

SET S(NEW) = 1 C**2
SET SC(NEW) = SC/2
S2
TIME UPDATE SC
SC(NEW) = SC + SRDT
SCALED 1/2PI C**2/SEC
S3
TIME UPDATE SR
SR(NEW) = SR + R**2
SCALED 1/2PI**2 C**2/SEC**2
WHERE R = .000012 (C/SEC)**2
DOES SR(NEW)
EXCEED (.225 C/SEC)**2?
NO
YES
SET SR(NEW) = (.225 C/SEC)**2
SET SC(NEW) = SC/2
CP
SAVE NEW SR
ARE ALL FILTERS UPDATED?
NO
TF TIME UPDATES1
0002
YES
* START TIME UPDATE OF PHASE ESTIMATE
LOAD REGISTERS WITH
ADDRESSES OF TEMP, STATION
VECTOR, RIJ, PRDR, PR AND P
SET UP COUNTER TO CYCLE EACH
STATION
SET UP COUNTER FOR 3 FREQ


S1
START UPDATE FOR EACH STATION
GET ADDRESSES OF TEMP, STATION VECTOR AND RIJ FOR MATRIX 3D
FORM TEMP = S X RIJ TO GET SL2 = S DOT R2, SL3 = S DOT R3
BSV
MATRIX 3D
INCREMENT STATION VECTOR ADDRESS BY 6 FOR NEXT STATION
COMPUTE PRDR FOR THIS STATION
PRDR = -(V3*SL3 + V2*SL2)/ (SL2**2 + SL3**2)**.5
SCALED 1/4PI IN 13.6 C/SEC
IS THIS PRDR FOR THE BASE STATION?
NO
YES
ADD THIS PRDR TO THE BOTTOM OF A NINE ELEMENT TABLE THAT KEEPS THE LAST NINE VALUES OF PRDR FOR THE BASE STATION. THE PREVIOUS ENTRIES ARE MOVED UP IN THE TABLE AND THE OLDEST IS DELETED
S4
FORM STATION NUMBER - BASE STATION NUMBER TO GET THE TIME T BETWEEN THE BASE STATION BURST AND THIS STATION'S BURST
THIS NUMBER WILL BE USED TO FORM PRDR OF THIS STATION NOW MINUS PRDR OF BASE AT TIME NOW - T
IF THE BASE IS A LOWER STATION NUMBER THAN THIS STATION THE DIFFERENCE POINTS TO THE CORRECT TERM IN THE PRDR(BASE) TABLE AS THE ENTRY FOR TIME (NOW) HAS ALREADY BEEN MADE

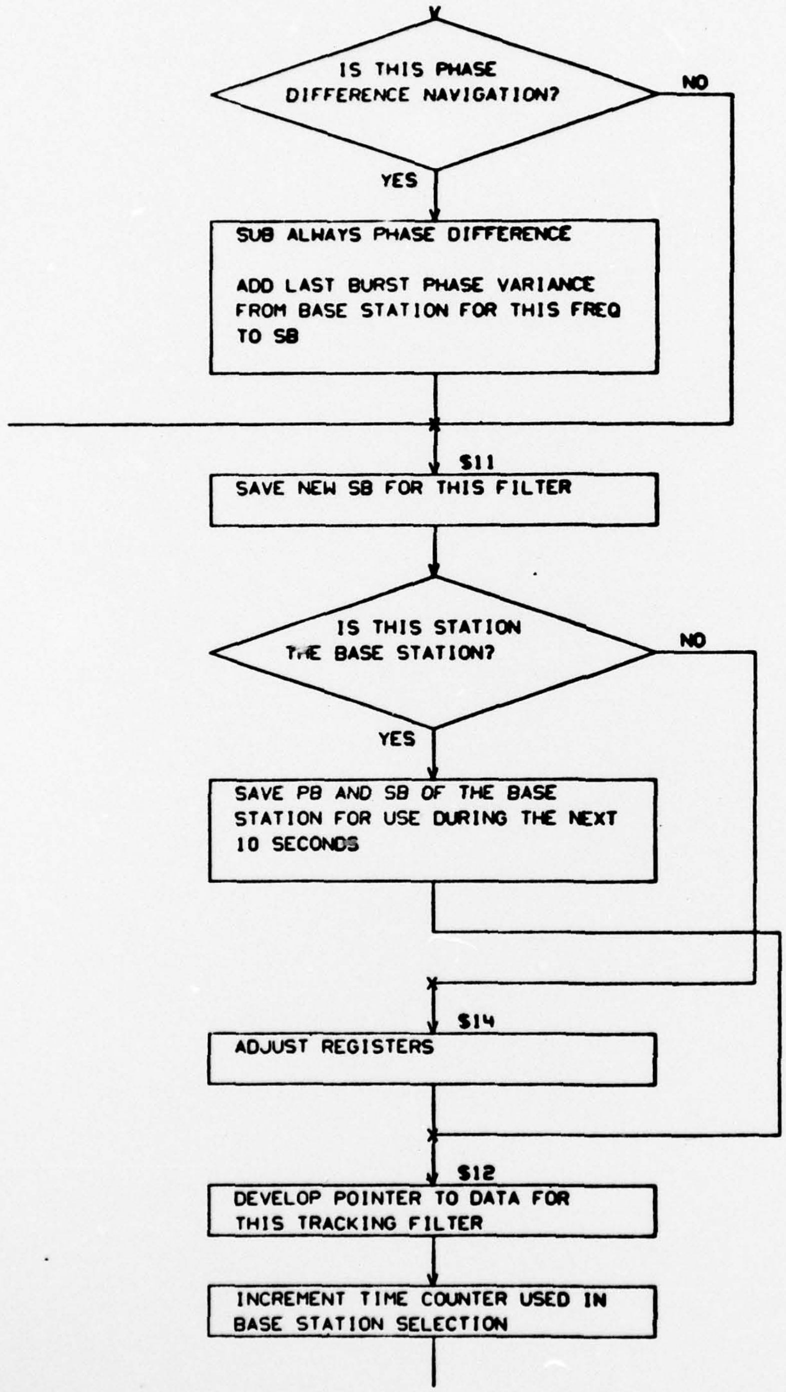

IS THE BASE STATION NUMBER LESS THAN THIS STATION NUMBER?
YES
NO
IS THIS THE BASE STATION?
YES
NO
THE BASE STATION PRDR FOR TIME (NOW) HAS NOT BEEN COMPUTED YET THE FIRST ENTRY IN THE TABLE IS FOR THE PREVIOUS BURST SO DECREMENT STATION - BASE NUMBER BY 1 TO CORRECT FOR THIS
$10
ADD 8 TO THE STATION - BASE NUMBER TO PUT IT IN THE RANGE OF 1 TO 8 WHERE 8 = 10 SEC AND IMPLIES THIS IS THE BASE STATION
$5
IS THIS PHASE DIFFERENCE NAVIGATION?
NO
$6
0006
YES
SUB ALWAYS PHASE DIFFERENCE
FORM PRDR FOR THIS SET OF THREE TRACKING FILTERS (3 FREQ) WHERE PRDR = PRDR (THIS STATION) MINUS PRDR (BASE)


$6
SAVE PRDR FOR THIS SET OF THREE TRACKING FILTERS (3 FREQ)
NOTE - ALL PRDR'S ARE COMPUTED FOR THE 13.6 FREQ ONLY AND CONVERTED TO THE OTHER FREQUECIES WHEN NEEDED
$2
TIME UPDATE PHI ESTIMATE (P)
P(NEW) = P + (PR + F*PRDR)*DT
SCALED B10 IN CYCLES
F = RATIO OF THIS FREQ TO 13.6
HAS P FOR ALL THREE FREQUENCIES BEEN UPDATED?
NO
YES
HAVE ALL STATIONS BEEN UPDATED?
NO
$1
0004
YES
* START TRACKING FILTER MEASUREMENT UPDATE
* USE BURST PHASE AND VARIANCE TO UPDATE
* THE TRACKING FILTERS OF THE THREE STATIONS
MEASUREMENT UPDATE
USE STATION COUNTER (= NUMBER OF STATION THAT JUST TRANSMITTED 10.2) AND FREQ NUMBER TO GET THE NUMBER OF THE STATION THAT JUST TRANSMITTED THIS FREQUENCY


IS THIS STATION IN THE LIST OF AVAILABLE STATIONS?
NO
$9
0014
YES
IS THIS FREQUENCY 11.3?
NO
$13
0008
YES
THE RAW H = Q(10.2)*Q(13.6)* Q(11.3) SCALED B3 FOR THE STATION THAT JUST TRANSMITTED 11.3 IS NOW AVAILABLE (RAW H IS COMPUTED IN END BURST WITH Q)
IS THIS RAW H FOR THE BASE STATION?
NO
$84
0008
YES
SET UP TO TURN SIGNAL LOSS LAMP ON THE C/I PANEL OFF
IS H RAW GREATER THAN .0078?
YES
NO
CHANGE SET UP TO TURN LAMP ON BECAUSE THE BASE STATION IS WEAK
$83
SAVE STATE OF SIGNAL LOSS LAMP FOR C/I PROGRAM



$84
COMPUTE H BURST
H BURST(NEW) = H BURST
+ .1*(H RAW - H BURST)
SCALED B3
$13
READ BURST PHASE PB FOR THIS
STATION AND FREQUENCY
IS THIS PHASE
DIFFERENCE NAVIGATION?
NO
YES
SUB ALWAYS PHASE DIFFERENCE
SUBTRACT LAST BURST PHASE FROM
BASE STATION FOR THIS FREQ FROM
PB
$10
SAVE NEW PB FOR THIS FILTER
READ BURST PHASE VARIANCE SB FOR
THIS STATION AND FREQUENCY
COMPUTE SB + (.005 C)**2
NOTE - SB + (.005 C)**2 WILL BE
A NEGATIVE NUMBER IF IT
EXCEEDS 1 C**2 WHICH IS
USED AS A MARKER INDICA-
TING AN INVALID MEASURE-
MENT
IS THIS A VALID MEASUREMENT?
NO
$11
0009
YES


IS THIS PHASE DIFFERENCE NAVIGATION?
NO
YES
SUB ALWAYS PHASE DIFFERENCE
ADD LAST BURST PHASE VARIANCE FROM BASE STATION FOR THIS FREQ TO SB
S11
SAVE NEW SB FOR THIS FILTER
IS THIS STATION THE BASE STATION?
NO
YES
SAVE PB AND SB OF THE BASE STATION FOR USE DURING THE NEXT 10 SECONDS
S14
ADJUST REGISTERS
S12
DEVELOP POINTER TO DATA FOR THIS TRACKING FILTER
INCREMENT TIME COUNTER USED IN BASE STATION SELECTION

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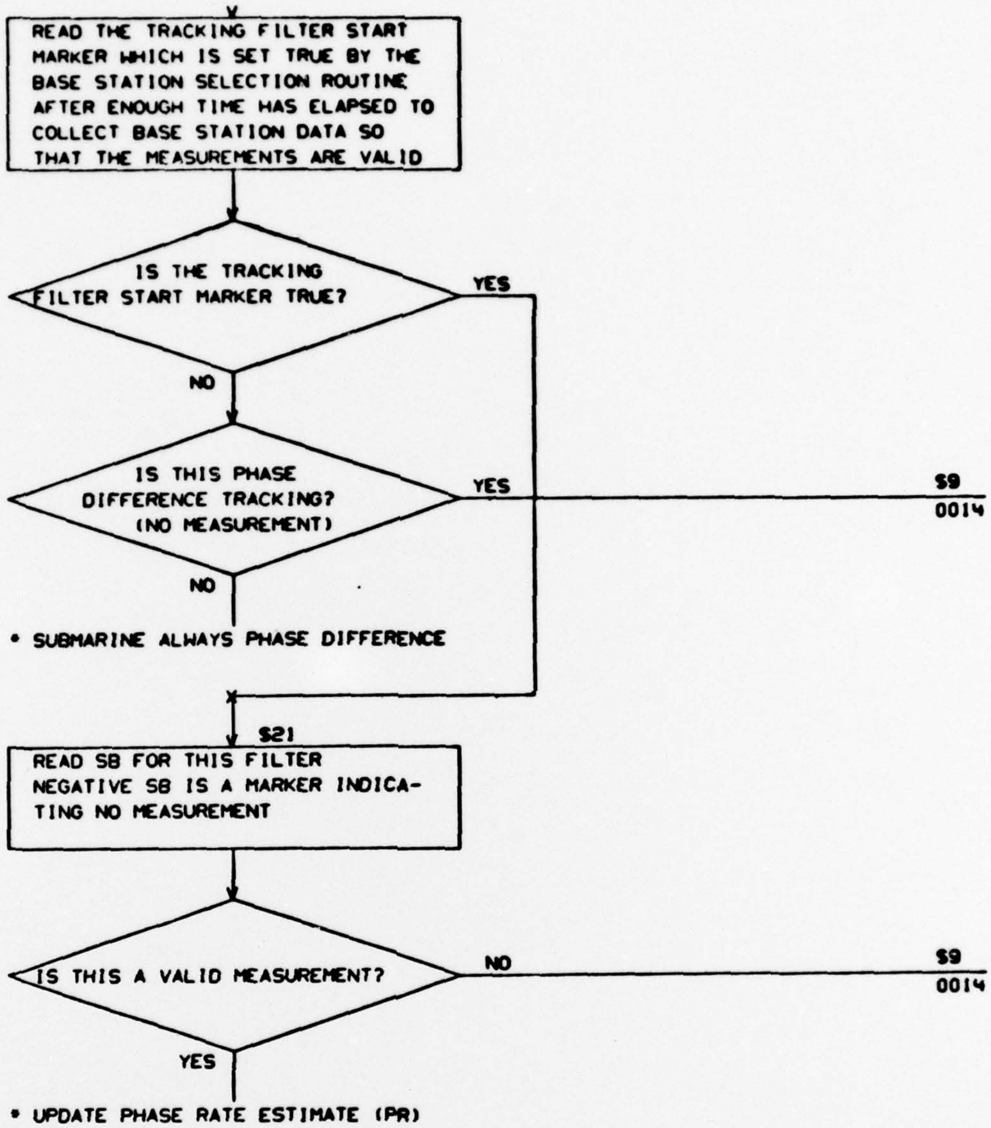
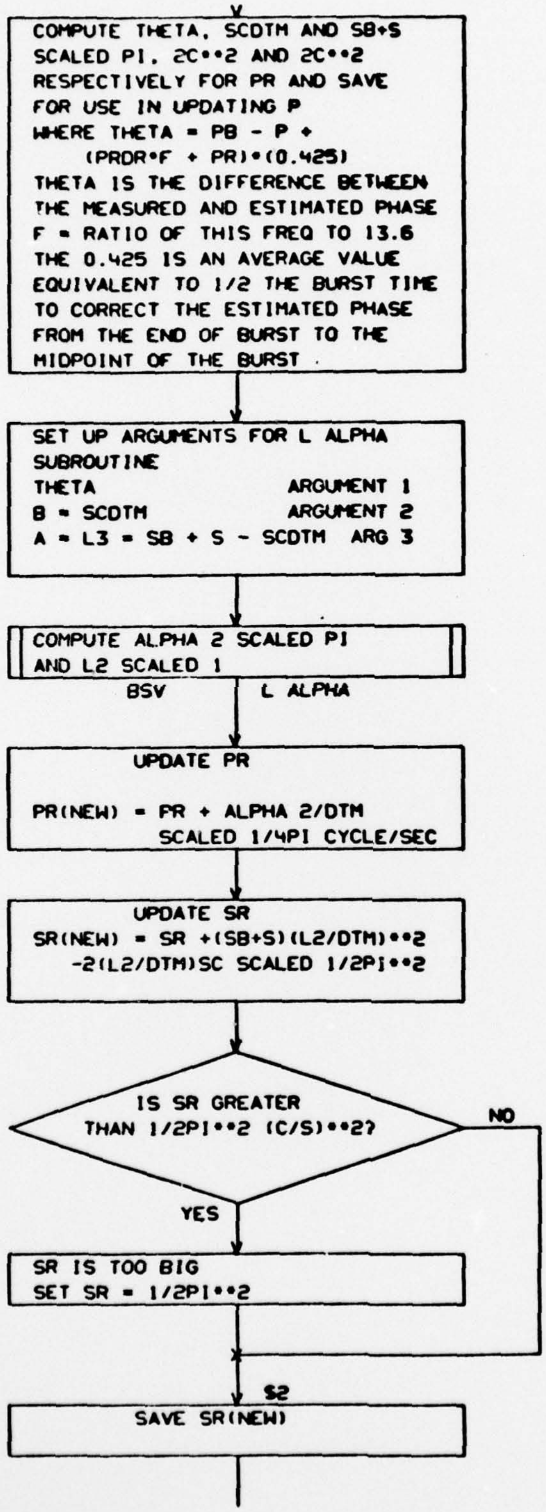
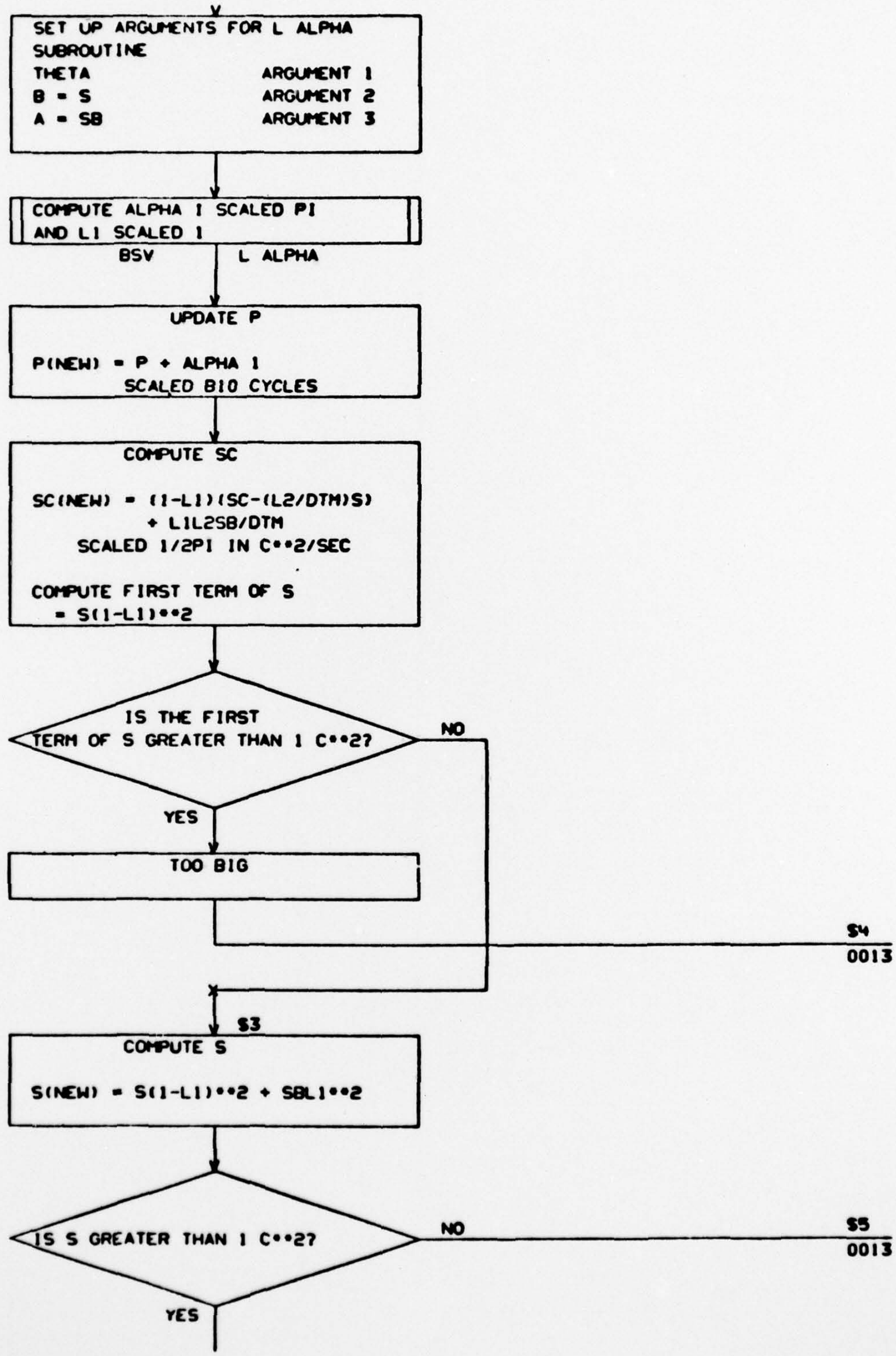

READ THE TRACKING FILTER START MARKER WHICH IS SET TRUE BY THE BASE STATION SELECTION ROUTINE AFTER ENOUGH TIME HAS ELAPSED TO COLLECT BASE STATION DATA SO THAT THE MEASUREMENTS ARE VALID
IS THE TRACKING FILTER START MARKER TRUE?
YES
NO
IS THIS PHASE DIFFERENCE TRACKING? (NO MEASUREMENT)
YES
S9
0014
NO
* SUBMARINE ALWAYS PHASE DIFFERENCE
S21
READ SB FOR THIS FILTER NEGATIVE SB IS A MARKER INDICATING NO MEASUREMENT
IS THIS A VALID MEASUREMENT?
NO
S9
0014
YES
* UPDATE PHASE RATE ESTIMATE (PR)


COMPUTE THETA, SCDTM AND SB+S
SCALED PI, 2C**2 AND 2C**2
RESPECTIVELY FOR PR AND SAVE
FOR USE IN UPDATING P
WHERE THETA = PB - P +
(PRDR*F + PR)*(0.425)
THETA IS THE DIFFERENCE BETWEEN
THE MEASURED AND ESTIMATED PHASE
F = RATIO OF THIS FREQ TO 13.6
THE 0.425 IS AN AVERAGE VALUE
EQUIVALENT TO 1/2 THE BURST TIME
TO CORRECT THE ESTIMATED PHASE
FROM THE END OF BURST TO THE
MIDPOINT OF THE BURST
SET UP ARGUMENTS FOR L ALPHA
SUBROUTINE
THETA ARGUMENT 1
B = SCDTM ARGUMENT 2
A = L3 = SB + S - SCDTM ARG 3
COMPUTE ALPHA 2 SCALED PI
AND L2 SCALED 1
BSV
L ALPHA
UPDATE PR
PR(NEW) = PR + ALPHA 2/DTM
SCALED 1/4PI CYCLE/SEC
UPDATE SR
SR(NEW) = SR +(SB+S)(L2/DTM)**2
-2(L2/DTM)SC SCALED 1/2PI**2
IS SR GREATER
THAN 1/2PI**2 (C/S)**2?
NO
YES
SR IS TOO BIG
SET SR = 1/2PI**2
S2
SAVE SR(NEW)


SET UP ARGUMENTS FOR L ALPHA SUBROUTINE
THETA ARGUMENT 1
B = S ARGUMENT 2
A = SB ARGUMENT 3
COMPUTE ALPHA 1 SCALED PI AND L1 SCALED 1
BSV
L ALPHA
UPDATE P
P(NEW) = P + ALPHA 1 SCALED B10 CYCLES
COMPUTE SC
SC(NEW) = (1-L1)(SC-(L2/DTM)S) + L1L2SB/DTM
SCALED 1/2PI IN C**2/SEC
COMPUTE FIRST TERM OF S = S(1-L1)**2
IS THE FIRST TERM OF S GREATER THAN 1 C**2?
NO
YES
TOO BIG
S4
0013
S3
COMPUTE S
S(NEW) = S(1-L1)**2 + SBL1**2
IS S GREATER THAN 1 C**2?
NO
S5
0013
YES

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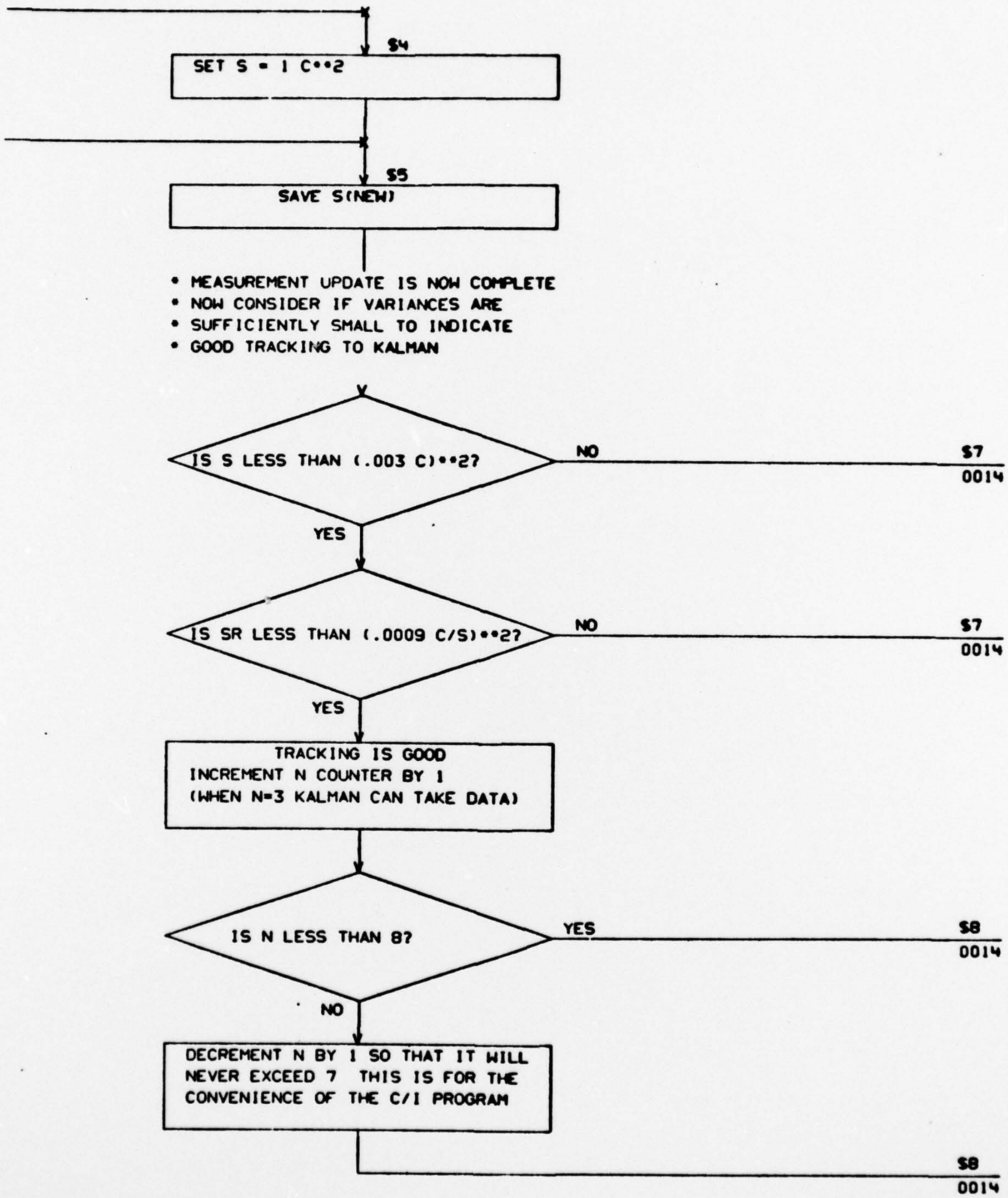
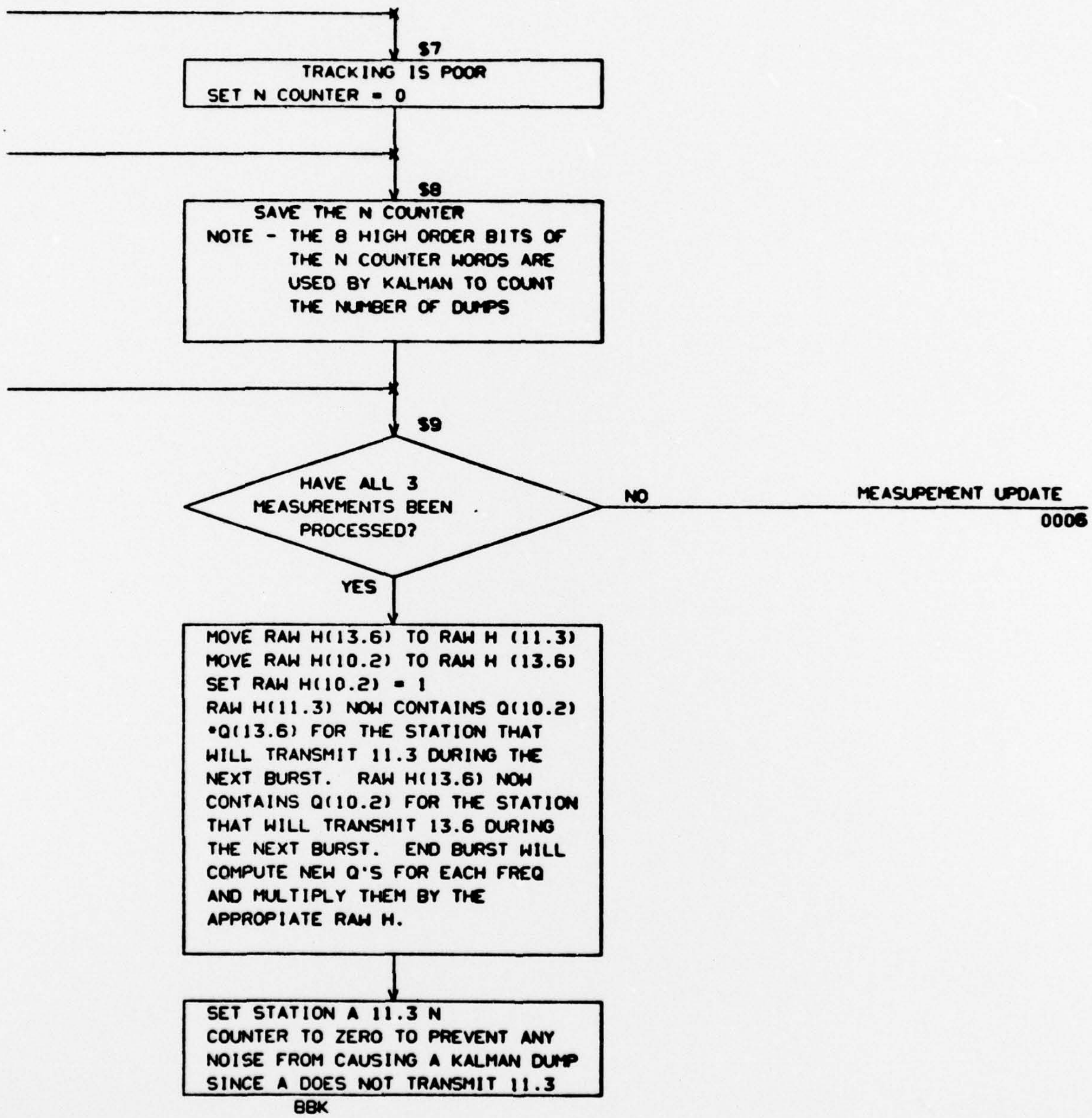
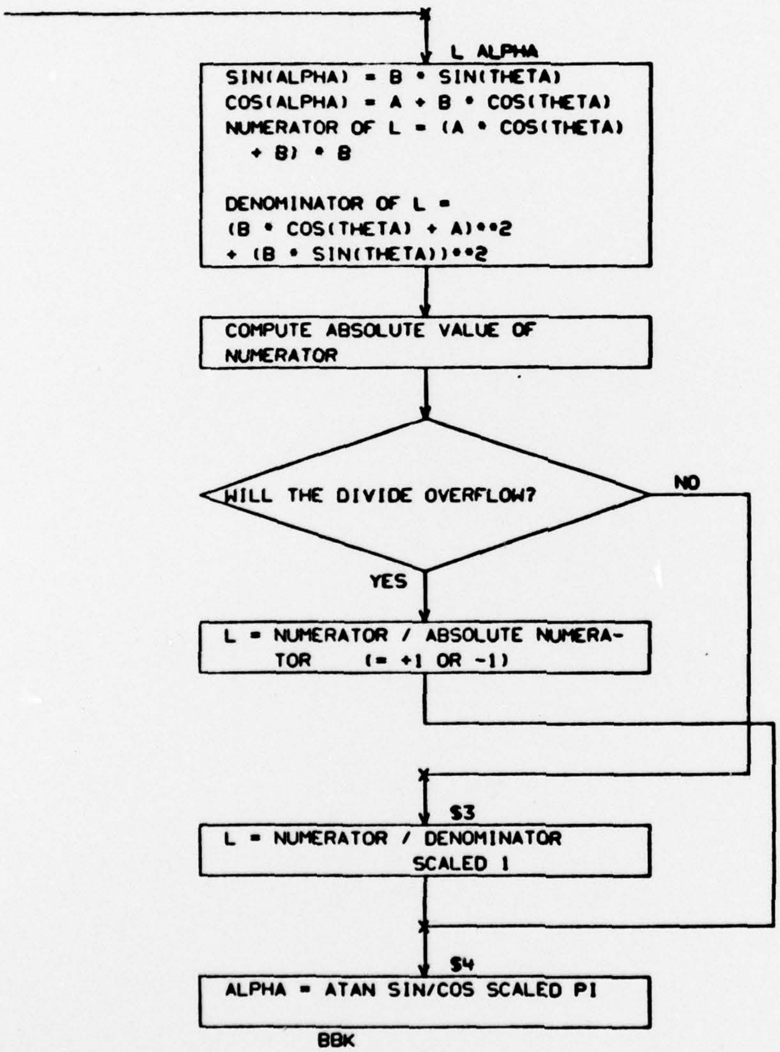

$4
SET S = 1 C**2
$5
SAVE S(NEW)
• MEASUREMENT UPDATE IS NOW COMPLETE
• NOW CONSIDER IF VARIANCES ARE
• SUFFICIENTLY SMALL TO INDICATE
• GOOD TRACKING TO KALMAN
IS S LESS THAN (.003 C)**2?
NO
$7
0014
YES
IS SR LESS THAN (.0009 C/S)**2?
NO
$7
0014
YES
TRACKING IS GOOD
INCREMENT N COUNTER BY 1
(WHEN N=3 KALMAN CAN TAKE DATA)
IS N LESS THAN 8?
YES
$8
0014
NO
DECREMENT N BY 1 SO THAT IT WILL
NEVER EXCEED 7 THIS IS FOR THE
CONVENIENCE OF THE C/I PROGRAM
$8
0014



S7
TRACKING IS POOR
SET N COUNTER = 0
S8
SAVE THE N COUNTER
NOTE - THE 8 HIGH ORDER BITS OF THE N COUNTER WORDS ARE USED BY KALMAN TO COUNT THE NUMBER OF DUMPS
S9
HAVE ALL 3 MEASUREMENTS BEEN PROCESSED?
NO
MEASUPEMENT UPDATE
0006
YES
MOVE RAW H(13.6) TO RAW H (11.3)
MOVE RAW H(10.2) TO RAW H (13.6)
SET RAW H(10.2) = 1
RAW H(11.3) NOW CONTAINS Q(10.2) *Q(13.6) FOR THE STATION THAT WILL TRANSMIT 11.3 DURING THE NEXT BURST. RAW H(13.6) NOW CONTAINS Q(10.2) FOR THE STATION THAT WILL TRANSMIT 13.6 DURING THE NEXT BURST. END BURST WILL COMPUTE NEW Q'S FOR EACH FREQ AND MULTIPLY THEM BY THE APPROPIATE RAW H.
SET STATION A 11.3 N COUNTER TO ZERO TO PREVENT ANY NOISE FROM CAUSING A KALMAN DUMP SINCE A DOES NOT TRANSMIT 11.3
BBK

```
*                         L ALPHA SUBROUTINE
*
* THIS ROUTINE WILL ACCEPT 3 ARGUMENTS (THETA, B AND A)
* AND RETURN ALPHA AND L
*
```



## 3.3 COMPUTER SUBPROGRAM ENVIRONMENT

### 3.3.1 Tracking Filter Tables

a) Frequency Ratio Table. The Frequency Ratio Table is used to convert PHI DOT DR from 13.6 cycles per second to the appropriate frequency.

The table has three entries that consist of the ratio of the selected frequency to the 13.6 frequency. The table has the usual order of 10.2, 13.6 and 11-1/3. The official label of this table is TF LAMBDA CONSTANT TABLE.

b) Station Location. This table contains the location of all existing OMEGA transmitting stations. Each location is specified as a three-element geocentric position vector. The first entry is for station A. The table is defined in detail in the listing. The official name of this table is STATION VECTOR TABLE.

### 3.3.2 Temporary Storage

The Tracking Filter program requires six words of temporary storage in addition to that storage used in the R15 pushdown stack.

### 3.3.3 Input/Output Formats

Not applicable.

### 3.3.4 Required System Library Subroutines

| Subroutine | Functional Description (Section 3.1.3) | Flow Diagram | Subprogram Design Document (by Volume) |
|---|---|---|---|
| ATAN | f-2 | L ALPHA Sub | XII Common Subroutines |
| MATRIX 3D | c-1 | P4/$1+1 | XII Common Subroutines |
| SIN-COS | f-1 | L ALPHA (Page 15) | XII Common Subroutines |
| SQRT | c-2 | p4/$1+4 | XII Common Subroutines |